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Modelling Public Security Operations

Evaluation of the Holistic Security Ecosystem (HSE) Proof-of-Concept

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Abstract

More so than engineered systems, human factors, and specifically having humans-in-the-loop, can lead to unforeseen behaviours resulting in unexpected organizational failures. In the world of emergency response, these failures may be related not only to response activities, but also to information processing and sharing that consequently undermine the organizational ecosystems' situational awareness of unfolding events. The TIF project, Modelling Public Security Operations, has the goal of accounting for the human factor by more fully exploring its inherent complexity through experiments and simulations. This work reviews the development of a new capability in this area using computer simulation, as well as the lessons learned from this effort. It represents a detailed proof-of-concept into how human factors can be explored through multi-agent systems. The modeling and simulation challenge remains that more research on human factors must be conducted, including work to support improved validation methods for computer human-factor models

Résumé

Plus que les systèmes sophistiqués, les facteurs humains, et plus particulièrement lorsque des humains interviennent, peuvent mener à des comportements imprévus entraînant des échecs organisationnels imprévus. Dans le monde des interventions d'urgence, ces échecs peuvent être reliés non seulement aux activités d'intervention, mais aussi au traitement et à l'échange de l'information qui minent la capacité de l'organisation à jauger la situation à mesure qu'elle évolue. Le projet FIT, la modélisation des opérations de sécurité publique, vise à tenir compte du facteur humain en examinant plus amplement sa complexité inhérente au moyen d'expériences et de simulations. Le présent travail consiste à examiner le développement d'une nouvelle capacité dans ce domaine au moyen d'une simulation informatisée ainsi que des leçons retenues de cet exercice. Il valide le principe selon lequel les facteurs humains peuvent être étudiés au moyen de systèmes multi-agents. Modélisation et simulation ou pas, plus de recherches sur les facteurs humains doivent être faites, y compris des travaux pour étayer de meilleures méthodes de validation pour les modèles informatisées des facteurs humains.

Executive summary

Modelling Public Security Operations: Evaluation of the Holistic Security Ecosystem (HSE) Proof-of-Concept

Alexis Morris; William Ross; Mihaela Ulieru; DRDC CSS CR 2012-026; DRDC CSS December 2012

Introduction: This report summarizes and evaluates research performed by the University of New Brunswick (UNB) in the context of the DRDC project, "*Modelling Public Security Operations*," which aims to investigate decision-making in complex meta-organizations. The UNB component of this initiative has involved the design and implementation of a simulation approach, the Holistic Security Ecosystem (HSE) simulation, for representing organizations and the decision-making process and for simulating the impact of key social, cognitive, and informational factors on the joint effectiveness of a security ecosystem.

Results: The Holistic Security Ecosystem (HSE) portion of the DRDC project was tasked with the goal of examining joint-organizational systems from both a top-down (i.e., individual) and bottom-up (i.e., system) perspective. It focused on the development of a computer-simulation approach to explore the effect of key social, cognitive, and informational factors present in individual agents (i.e., the individual-level) on inter-organizational efforts (i.e., the system-level), in particular consensus achievement through information sharing. The focus of the simulation was on whether or not agents with bounded rationality, only witnessing portions of the unfolding situation, could, in conjunction with other agents and based on the simulation settings collectively agree that a threat to the harbour was imminent. The experimental results show that the cognitive factor has the greatest impact on consensus achievement, though social and informational factors are also important.

Significance: The research to arrive at the HSE tool was conducted in six stages, as presented in previous deliverables, and culminates with a detailed multi-agent simulation involving high-functioning work-practice agents, following organizational workflows, and being influenced by social, cognitive, and informational factors. Such a simulation can help to elicit important information about how these core factors relate to one another and ultimately impact the system. This suggests that continued exploration using computer simulations is beneficial. Additionally, the HSE approach provides a core methodology for constructing such simulations, and has the potential to be adapted for future experiments at relatively low cost.

Future plans: The lessons learned from this work are threefold: (i) more focus on human factors through simulation is necessary to better explore the complex interplay between human factors and meta-organizational design; (ii) more focus on human-factor model validation is needed to add credibility to the results.; and (iii) more information on organizational procedures is needed to create meaningful functional models that can be "operationalized." These will lead to an improved understanding of the human element and its impact on joint-organizational endeavours.

Sommaire

Modélisation des opérations de sécurité publique : Évaluation de la validation de principe des écosystèmes holistiques de sécurité

Alexis Morris; William Ross; Mihaela Ulieru; DRDC CSS CR 2012-026; RDDC CSS Décembre 2012

Introduction : Ce rapport résume et évalue les recherches effectuées par l'Université du Nouveau-Brunswick (UNB) dans le contexte du projet de modélisation des opérations de sécurité publique du RDDC, qui vise à étudier la prise de décisions dans des méta-organisations complexes. Dans cette étude, les travaux de l'UNB comportaient la conception et l'instauration d'une approche de simulation, la simulation d'écosystèmes holistiques de sécurité (EHS), pour représenter les organisations et le processus de prise de décisions et pour simuler les répercussions des principaux facteurs sociaux, cognitifs et informationnels sur l'efficacité globale d'un écosystème de sécurité.

Résultats : La partie du projet de RDDC portant sur les écosystèmes holistiques de sécurité (EHS) a été attribuée dans le but d'examiner les systèmes organisationnels conjoints dans une perspective descendante (individuelle) et ascendante (système). Elle portait sur le développement d'une approche de simulation informatisée pour explorer l'effet des principaux facteurs sociaux, cognitifs et informationnels présents chez les agents individuels (au niveau individuel) sur les efforts inter organismes (au niveau du système), plus particulièrement l'intervention d'un consensus par échange d'information. La simulation visait essentiellement à déterminer si les agents à la rationalité limitée, témoins seulement de certains aspects de la situation, pourraient, conjointement avec d'autres agents et selon le contexte de la simulation, s'entendre sur le fait que le port était menacé. Les résultats expérimentaux montrent que c'est le facteur cognitif qui a la plus forte incidence sur l'intervention d'un consensus, bien que les facteurs sociaux et informationnels soient aussi importants.

Importance : La recherche qui a mené à l'outil EHS a été menée en six étapes, comme il est expliqué dans les documents précédents, et culmine avec une simulation multi-agents détaillée comportant des agents de pratiques de travail de haut niveau, suivant le déroulement des opérations et étant influencés par des facteurs sociaux, cognitifs et informationnels. Une telle simulation peut contribuer à obtenir de l'information importante sur la façon dont ces principaux facteurs sont liés entre eux et finissent par influer sur le système, ce qui laisse penser que la poursuite de l'exploration au moyen de simulations informatisées est utile. De plus, l'approche EHS procure une méthodologie de base pour construire de telles simulations et pourrait être adaptée à d'autres expériences à un coût relativement bas.

Perspectives : Les leçons retenues de ces travaux sont triples : i) il est nécessaire de se pencher davantage sur les facteurs humains au moyen de simulations pour mieux explorer les interactions entre les facteurs humains et la conception des méta-organisations; ii) il faut s'employer davantage à valider les modèles de facteurs humains pour accroître la crédibilité des résultats et iii) il nous faut plus d'information sur les procédures organisationnelles pour créer des modèles fonctionnels valables qui puissent être « opérationnalisés ». Ils permettront une meilleure compréhension de l'élément humain et de ses répercussions sur les entreprises conjointes.

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1 Introduction

This deliverable summarizes and evaluates research performed by the University of New Brunswick (UNB) in the context of the DRDC TIF initiative, "*Modelling Public Security Operations*," which aims to investigate decision-making in complex meta-organizations [TIF Proposal]. The UNB component of this initiative has involved the design and implementation of a simulation approach, the Holistic Security Ecosystem (HSE) simulation, for representing organizations and the decision-making process and for simulating the impact of key social, cognitive, and informational factors on the joint effectiveness of a security ecosystem[1].

The HSE simulation environment has been described and presented along with methodologies for organization and human-factor modeling in Deliverables 1 to 6, [UNB1-UNB4]. This previous work considered a joint-operational harbour-security scenario in which consensus achievement, based on information sharing, was examined across several dimensions. Results indicate that cognitive factors have the greatest impact on joint meta-organizational effectiveness, which supports the findings of project research partners, [UofO5].

The current deliverable evaluates the HSE simulation in the light of existing literature, as well as comparing it to an in-vivo experimental approach. It also highlights the strengths and weaknesses of the HSE approach using four criteria—utility, feasibility, relevance, and verifiability—and presents lessons learned in developing the HSE simulation.

1.1 Project Milestones

Below are the primary UNB outcomes for the TIF research on the development of tools, techniques, and best practices for modelling public security operations. (The current deliverable is highlighted.)

- Design of the HSE simulation (Oct 2009)
- Implementation of the HSE simulation (Jan 2010)
- Extension of the HSE simulation to include social, cognitive, and informational conceptual models (Sept 2010)
- Verification of the extended HSE simulation (Dec 2010)
- Analysis of the effect of key social, cognitive, and informational factors (Apr 2011)
- Analysis of the effect of security system relationship configurations on goal achievement (Aug 2011)
- *Evaluation of the HSE "proof of concept" (Feb 2012)*

[1] Ecosystem here refers to a temporary alliance of organizations working cooperatively toward a common objective.

2 Related Literature

The central concepts involved in the development of the HSE platform relate to six key disciplines. These are (i) action research, used to gather early data on the processes involved during the Harbour Siren (2009) exercise where the UNB team participated as academic observers; (ii) human-factor modelling, which was used in the selection of which human elements would be important to model, as well as the actual model development and validation; (iii) multi-agent system simulation, which involved the selection of tools from the literature for designing and implementing agent decision-making logic, communications, role-relationships, and task-activities; (iv) organizational modelling, which was used in considering the core policies, norms, and roles within organizations; (v) consensus modelling, which focuses on how consensus is achieved within multi-agent systems and was used after the UNB research shifted from response to threat detection; and (vi) soft-systems methodology research, which supported the use of agent-based systems, particularly with respect to having models of multiple competing but valid perspectives of reality. The sections below describe each domain in more detail, including relevant core literature, and highlight further how these have influenced the development of the HSE.

2.1 Action Research

There are multiple viewpoints on what constitutes action research; however, it may be said that action research involves developing an understanding of a process through participative engagement with the system-under-study. This may be considered depending on the system-under-study as first-person, second-person, or third-person methods, [Marshall]. First-person action research involves researchers' self-inquiry into their own lives. Second-person action research involves joint inquiry into issues of mutual concern to two parties, while third-person action research is used to discuss wide community systems, like organizations and inter-organizational partnerships. This process is iterative, and relates to the key phases of planning actions, taking actions, observations of those actions, and reflecting on what was learned, as a way to understand a system, [Altrichter]. Reflection is a key component, and action research requires a group of representatives in an organization to reflect on actions taken from their own experiences and to evaluate and ultimately manage those experiences, [Altrichter]. In more concrete terms, this is a process of several cyclical steps, as in [Gronhaug]: observation, interpretation, plan/action, observation of outcome, reflection, modified interpretation (explanation), and plan/action.

In terms of the HSE project, strict third-person action research was not followed, but a modified approach emerged in order to gain an understanding of the joint organizations involved in harbour safety and threat consensus modelling. In particular, the data gathering phases of the project involved the participation in the "Harbour Siren" exercise of 2009, where background (ethnographic) observation of harbour joint-consensus exercises was conducted as a first step. Internal team reflection and online investigation led to the development of an early HSE model. Further developments involved expert consultations and interviews of two ex-naval members on port processes, which led to a refined event timeline of the final simulation scenario and an understanding of important human factors. These were then discussed with a multi-disciplinary panel of experts to gain further insights. Ultimately, this resulted in the refinement of the consensus process model for a joint organization simulation with publish, observe, document, and risk-check cycle, as defined in the previous deliverables, [UNB1-4].

2.2 Human Factor Modelling

Human-factors research aims at understanding the effect of systems and their humans-in-the-loop, whether for computer interaction, organizations, or other complex socio-technical systems. Gaining an understanding of human behaviours involves interdisciplinary study on multiple levels, [Vicente]. These encompass the physical, psychological, social-team, organizational, and political levels of human behaviour, [Vicente], which describe systems in a framework for ergonomic studies. These levels intersect a vast body of research. For instance, third-party action research would take place at higher levels, such as the social-team level, or the organizational and political levels. Alternatively, disciplines like cognitive ergonomics, [Jamieson], and human-computer-interaction would target the lower levels: the physical, psychological, and social levels. Human-factors research aims to understand the human limits and causal relationships (with the environment).

In the HSE work, the human-factor levels have been described according to a seven-dimensional model, and have been used for the simulation and research on modelling social systems (such as culture, [Culture]). This seven-dimensional framework advocates that systems be viewed from the physical, individual, functional, structural, normative, social, and informational dimensions. The human factors include modelling stress, trust, risk factors, and cultural factors, as well as information observation and sharing, [UNB2, UNB3]. System dynamics diagramming is used to describe causal loops among these factors. System dynamics provides a vocabulary to describe the often fuzzy human factors in terms of their key components and relationships. It has been used to discuss many social phenomena, particularly for economic systems and supply-chain management, [Sterman]. This research presents this use of system dynamics for factors such as stress, [Stress], (where stress is a psycho-physiological human factor related to resources versus task demands). Risk has been described in terms of a number of factors related to the CAR model of competence, authority, and responsibility, [CARModel], as well as various event-related probabilities of perceived consequence and other factors, [UNB3].

2.3 Modelling and Simulation with Agents

Multi-agent systems represent a software design methodology and a discipline involving autonomously interacting programs (agents) as actors in a collaborative environment (simulated or otherwise). Agent technology has been used in multiple domains to model and simulate the phenomena involving interacting components, [Balaji]. These agents may be classified according to their degree of autonomy, proactiveness, reactiveness, and social ability, [Wooldridge]. Agent systems also allow for incorporating models of the human factors described previously. The physiological properties, such as aspects of stress, can be added to a model as well as the psychological aspects (e.g., trust) and the higher dimensions (i.e., social, organizational, and political). Social network theory, influence networks, distributed negotiation, economic modelling, and game theory all allow for exploring behavioural properties within complex social systems through agents, [Balaji, Shoham]. For example, in [Shoham], agents have been shown to model constraint satisfaction, optimization, social laws, cooperative and non-cooperative behaviours, social choice, and market theories. Other work on agent technologies involve architectures, languages, and programming frameworks, as described in [Bryson].

In terms of the influence of multi-agent system simulation on the developed HSE approach, there are several core points. First is modelling and simulating work practice with agents, [Brahms]. In this work a new architecture, programming language, and framework were introduced. This framework promoted agent design based on the concept of work-practice, i.e., that agents are not goal-driven, as is commonly considered in the agent community ([Jason, Brahms]), but both

action- and thought-oriented. Brahms agents fit into a class of agent architecture known as BDI, or belief-desires-intentions; an agent design methodology incorporating a processing engine based loosely on human information processing, [Rao, Wooldridge]. Such agents provide a notion of bounded rationality, i.e., that agent knowledge of the world is potentially incomplete, and therefore decisions are made based on what beliefs the agent has of the world. This knowledge may not necessarily map to the actual reality, allowing for agent models that are not all-knowing, but instead have degrees of decision-making abilities, i.e., some are more "in-touch" with a world situation (situationally aware) than others. These "facts and beliefs" used in the agent-decision process relate to human factors on a psychological level. In Brahms, plans and situated actions provide the work practice of agents and allow for inter-agent communication networks to be set in place through the standard "speech-acts" protocol, [Brahms].

Modelling based on normative behaviour has also been relevant in the HSE designs to model the human-factor reality at the social, organizational, and political levels. OperA provides a framework for modelling rules of behaviour that map to actual behavioural norms, [Dignum]. Functional roles and relationships are also definable through methodologies like OperA, and the HSE project makes use of these in understanding joint organizational-roles (described in the section below on organizational modelling).

Finally, the agent approach taken in HSE also makes use of system dynamics to define the causal relationships between variables, and how those variables interact during runtime. This mixed agent-based and system dynamics approach has been discussed in literature as a way to provide a "best-of-both-worlds" model that has both top-down understanding of processes (system dynamics) and bottom-up emergent results from collective interactions (agents). See, [Scholl], for more on the agent-based system dynamics literature.

2.4 Organizational Modelling

The research related to organizational modelling used during this project can be gathered into three main groups: enterprise architecture, business process modelling, and agent organizations. Each will be described below.

2.4.1 Enterprise Architecture

According to the Enterprise Architecture Research Forum, "Enterprise Architecture is the continuous practice of describing the essential elements of a socio-technical organization, their relationships to each other and to the environment, in order to understand complexity and manage change," [EARF]. It is used to improve the functioning, efficiency, and interoperability of the business itself. However, the important human element is missing from many enterprise architecture frameworks, which specify the views of interest and how they must be organized, [Handley]. For example, the British military uses MoDAF (Ministry of Defence Architectural Framework), [MoDAF], while the United States military uses DoDAF (Department of Defence Architectural Framework), [DoDAF], but neither expressly captures the variety of important human factors, for instance, the impact of operator stress on the system. They are used primarily to help with acquisitions and to support the integration of equipment capabilities, [DoDAF]. The former framework considers the strategic, operational, service-oriented, systems, acquisition, and technical views of the military, [MoDAF], while the latter explores the capability, data and information, operational, project, services, standards, and systems views, [DoDAF].

These frameworks describe the prescriptive view (i.e., how things work ideally), not the descriptive view (i.e., how things work in reality). Moreover, because the important human view is missing, these frameworks alone are not sufficient to analyse the social, cognitive, and

informational factors required in this project. Currently, these frameworks are also static representations that cannot be "run." However, recent work has attempted to make executable enterprise architectures for the purposes of improving organizational efficiency, [Baumgarten, Glazner], trying to model the behaviour of the organization, rather than focusing mainly on interoperability.

2.4.2 Business Process Modelling

The term business process modelling refers to "all activities relating to the transformation of knowledge about business systems into models that describe the processes performed by organizations," [Scholz-Reiter]. There are several reasons to model the business processes of an organization, but the primary reason is to improve organizational efficiency. Business processes can be viewed as a sequence of tasks, and the order in which the tasks are arranged is a critical design variable—more optimal arrangements lead to more efficient resulting structures, [Orman]. However, these may have unexpected consequences on other parts of the organization, including its people, its strategy, its environment, its culture, its information systems, and other processes, [Giaglis].

Various tools exist in support of business process modelling, including Intalio BPMS, [Intalio], and ARIS, [ARIS], and the standard visual representation is Business Process Modelling Notation (BPMN), which unlike UML that focuses on objects, examines an organization from a process perspective, [Owen]. This notation allows the modeller to capture the business processes, decision points, and data stored and exchanged within and across organizations.

Many tools allow for the creation of static BPMN-compliant workflows, but Intalio BPMS and ARIS also provide the ability to simulate the processes, by combining events, processes, and rules, [Intalio]. In addition, these tools are also well-suited for modelling the structure of the organization. For example, ARIS provides a set of metaclasses to describe any organization: Organizational Unit, Organization Unit Type, Position, Person, Person Type, Group, and Location, [Santos]. However, according to, [Glazner], ARIS is limited to the domain of information systems.

This modelling method is particularly appropriate for analysing the structural, functional, and normative aspects of an organization, where normative relates to the rules specified by the organization. However, it does not take into account human factors, such as stress, trust, and influence, nor does it simulate humans deviating from the norms. As such, it provides a useful communication mechanism (namely BPMN) and evidence that parameter tuning can be used to improve organizations, but this method alone is not sufficient to address the requirements of the project.

2.4.3 Agent Organizations

Unlike the other approaches examined in this subsection, an agent-based approach allows the effect of individual agent characteristics to be explored, [Borshchev]. Whenever two or more agents interact in the same environment, a society of agents exists, and, [Ferber], argues that elements of organizational structure, including "groups," "roles," and "organizations," can help provide the necessary structure to alleviate some of the challenges of classical agent-based systems (e.g., accurately modelling the problem being addressed).

A targeted effort to model organizations using agents is found in, [Dignum]. OperA (Organizations per Agent) is a non-executable modelling language that is used to describe the

interaction between different agents within an organization. It provides constructs to capture the structure of an organization in terms of roles and relationships, the interaction patterns between agents as workflows, and the organization's normative aspects using deontic logic. Deontic logic labels an action as being *obligatory*, *prohibited*, or *permissible*, but does not dictate which action an agent must choose. This flexibility allows agents to perform actions that do not strictly adhere to an organization's policies. Because it is non-executable, OperA was not sufficient as a stand-alone tool for the purposes of this project. However, for our first deliverable, [UNB1], OperA was used in conjunction with Brahms, which is executable, following the guidelines outlined in, [Putten].

2.5 Consensus Modelling

Group decision making is one of the core targets for the HSE system, as agents in the simulation must reach consensus of a threatening event. This form of distributed decision making has been considered in the literature from several perspectives. The game-theoretic approach to consensus modelling highlights some of the important properties of distributed agent simulation as a whole. The simulation could be cooperative, or non-cooperative, or have complete or incomplete information for its agents. Additionally, these agents may be either truthful or deceptive, [Shoham]. In all cases, agents act as utility maximizers for a specific kind of utility function. These functions may be designed so as to emerge certain properties in the simulation from a collective-society perspective. Different individual utility functions pertain to different agent strategies, including risk perceptions and willingness to take risky behaviours. These have been shown in various protocols, including agents forming contracts, making bribes to other agents, and mediatorship behaviours between agents, [Shoham].

The various strategies related to consensus modelling include particular voting protocols and the types of core leadership in place. There are a number of voting protocols, as seen in, [Shoham], but a common method involves the use of a simple majority. Other strategies for decision making involve principles of negotiation such as strategic negotiation, and principles of alternating offers, [Kraus, Rubenstein]. Further literature shows a number of mathematical approaches to discuss the consensus problem, many of which use dynamic system modeling, such as, [Fedrizzi2010, Campanella], and notions of opinion dynamics, [Blondel].

The HSE model for consensus uses a simple-majority rule to determine the measure of consensus regarding the threat-level at a given time during the simulation. This approach considers a coalition of agents for making the consensus decision, which is selected during analysis. Moreover, multiple views of consensus are possible, and all are captured, depending on the analyst's definition of what percentage-threshold constitutes consensus, [UNB4]. The HSE approach is deception-free, i.e., agents are not allowed to lie about information being shared, making it (in the rhetoric of agent literature) a cooperative information-sharing game.

2.6 Soft Systems Methodology

The Soft Systems Methodology (SSM) is premised on the idea that there is not one valid perspective of "reality," but rather multiple interacting perspectives, [Checkland1, Checkland2]. These may be quite contrary, but equally valid; for example, one person's "information hoarding" is another's "protection against legal action." These interacting perspectives represent "messy" problems for management precisely because soft factors (e.g., psychology and culture) tend to dominate over "hard" factors (e.g., technical specifications), resulting in poorly-defined problems, [Checkland1].

Checkland's seven-step SSM offers a methodology to overcome these messy problems by analysing reality from multiple perspectives and proposing a change to the organization that is culturally feasible, taking into account "the particular history, culture, and politics of the people involved," [Checkland2]. The seven points in this methodology are as follows, [Checkland2]:

(i) A perceived problematic situation exists;
(ii) It will be perceived differently by people with different worldviews;
(iii) It will contain people trying to act purposefully (intention);
(iv) To understand this problem, make models of purposeful activity as perceived by different worldviews;
(v) Use models as a source of questions to ask of the problematical situation, thus structuring a discussion about changes which are both (a) desirable (given these models) and (b) feasible (culturally);
(vi) Find versions of the to-be-changed situation which different worldviews could live with;
(vii) Implement changes to improve (be ready to start the process again).

This methodology is well-aligned with the HSE approach. Because it uses agent-based societies, the HSE approach is able to address points (ii) - (iv) above. BDI agents have their own perspective of reality which exists as a set of beliefs. In the simulation, agents may perceive different indicators, but they also have different beliefs regarding the importance (or potential risk) of an indicator (ii). This in turn will guide them in deciding how to share (or not) the indicator with other agents (iii). With the ecosystem and organizational agents modelled, the effect of various "soft" factors on the desired goal of the system can then be simulated (iv). When a particular problematic situation is perceived, for example, information hoarding (i), the HSE can facilitate points (v) and (vi) by enabling the exploration of different alternatives in arriving at a desirable solution (e.g., increased situational awareness).

2.7 Literature Summary

The above discussion has shown how diverse these fields can be and highlights the need for more interdisciplinary research on human factors within simulations. While different tools and approaches provide important pieces, none was sufficient by itself to explore the impact of social, cognitive, and informational factors. However, the HSE approach combines several of these techniques. For instance, OperA was used to represent organizational structures and contracts between organizations (deontic logic). BPMN was used to capture internal processes within organizations. This had the added feature of being easily understood by a large audience, which helped during the verification and validation workshop. A multi-agent systems approach, incorporating the BDI architecture (i.e., Brahms), was used to represent individual differences in perceiving the environment, which influenced agent responses. As for the human-factor models, system dynamics causal loop diagrams were employed to capture behaviour and for communicating these models to experts for validation purposes. More information on the HSE multi-dimensional approach is found in Deliverables 1 to 6, [UNB1-UNB4].

3 Related Approach (University of Ottawa)

The main focus of this report is to assess the merits of using computer simulation, specifically the HSE approach, to glean insights into public security operations by modelling and simulating cognitive, social, and informational factors. However, there are other approaches for investigating such factors, particularly in-vivo simulation, which has been used by our project partner, the University of Ottawa (UofO). This section will compare the two approaches based on the project work delivered to date ([UofO1-UofO5], for UofO and, [UNB1-UNB4], for UNB). Specifically, it will discuss the two approaches, the area of investigation considered by each group, and the experiments carried out. The main differences and similarities between the two approaches are summarized in Table 1.

Table 1 Approach Comparison

University of Ottawa	**University of New Brunswick**
Simulation approach • In-vivo simulation *Area of investigation* • Shared decision making: coordination, cooperation, and collaboration • 0 to +1 event timeline *Experiment* • Roles (Participants) • Multiple scenarios • Human factors related to shared decision making and situational complexity • Variables: coordination vs. collaboration; homogenous vs. mixed pods • Results: Qualitative analysis	*Simulation approach* • Agent-based simulation *Area of investigation* • Consensus achievement (information sharing): cognitive, social, and informational factors • -2 to 0 event timeline *Experiment* • Roles (Level-0) • Single scenario • Human factors related to cognitive, social, and informational factors • Variables: randomized vs. constant cognitive, social, and informational factors; • Results: Quantitative analysis

3.1 Simulation Approach & Area of Investigation

Both groups had a different mandate to fulfill within the project. UofO was tasked with research using in-vivo simulations to investigate meta-organizational shared decision making (SDM), while UNB was tasked with modelling public security operations using computer simulation to ultimately investigate consensus achievement. For context, in-vivo simulation is a process in which actual human participants are observed in real-time while they perform activities, and this assessment, in addition to qualitative surveys, was used by UofO to evaluate different SDM methods—specifically, coordination, cooperation, and collaboration—during the response to specific scripted events. Therefore, the event horizon of interest is from incident to response (0 to +1).

The work at UNB, based on the literature summary, focused on using a multi-agent simulation to model, first, response (early HSE) and, then, detection (final HSE), in which specific human aspects are simulated and their effect on goal achievement analysed. The event timeline for the work ultimately focused on preparation and detection leading up to an incident (-2 to 0). In this approach, individual agents represent humans, and their respective behaviour and beliefs can be tuned based on the discretion of the modeller. Rather than looking at specific humans, this approach attempts to explore human behavioural types and their impact on the system. For

example, what would happen if the majority of the agents were selfish? Would information be shared across the ecosystem? Even though these appear different, the strategies of coordination, cooperation, and collaboration could certainly impact the success of consensus achievement, and could be explored in computer simulations. Broadly, SDM is not limited to post-disaster. It can be used in the events leading up to a disaster to help achieve better situational awareness through information sharing.

3.2 Experiment Participants

For its in-vivo experiments, UofO used participants from the following organizations:

- Federal: Public Safety and Canadian Forces
- Provincial: Office of Disaster Management, Manitoba Health
- Municipal: Ottawa Public Health, Ottawa Fire Department, City of Ottawa

These participants performed specific tasks in relation to a complex scenario of an extreme event, and empirical data was collected (e.g., behaviour, self-report, and observations) from the in-vivo sessions. Three possible scenarios were considered: a train derailment and chemical contamination, a cyber-attack and blackout, and a radiological “dirty bomb.”

For the computer simulations, the UNB implemented agents, from 20 different areas, were used and presented based on an initial level-0 diagram of harbour organizations. These were gathered after an extensive study of Canadian harbours, a planning session with two ex-naval members, and a verification and validation workshop and are seen below:

- Federal: Public Safety Canada, Canada Customs and Border Services Agency (CBSA), Transport Canada, Government Operations Centre (GOC), Coast Guard, Marine Communications and Traffic Service (MCTS), Joint Task Force Atlantic (JTFA), Queen’s Harbour Master, Marine Security Operation Centre (MSOC), RCMP
- Provincial: Police of Jurisdiction (provincial), Joint Emergency Operation Centre (EMOC),
- Municipal: Police of Jurisdiction (municipal), Medical Facility
- Public: Cargo Ships, Vessel of Interest, Protest Group, General Public, Media, Port Authority.

These agent actors participated in observing, documenting, risk checking, and communicating various problem-related indicators within the system, as will be described further in the next section. Following each experiment, the impact of various social, cognitive, and informational factors on consensus achievement was assessed. A single harbour security scenario was considered with two variations: originating domestically or offshore, each sharing many indicators but with key differences, unique to the particular variation of the threat event.

3.3 Human Factors

As shown in the Table, both the UofO and UNB approaches attempt to examine human factors. The ones analysed by UofO relate to the model developed by Lemyre et al., [UofO3], which explores the factors that categorize situation complexity and the inter-organizational approach used by the decision-makers (i.e., coordination, cooperation, and collaboration) based on the assets and time available.

- The *situational complexity*, categorized as simple, complicated, or complex, is affected by three key factors: (i) *impact,* i.e., scope, severity, timing, media involvement, and political process; (ii) *uncertainty*, i.e., novelty, anticipation & planning, lack of information flexibility of frameworks, changing context, and new organizations & partners; and (iii) *vulnerability*, i.e., economic development, social capital, competence, and communication
- Moderators (that can affect which approach is used): *assets* and *time* available to decision makers
- Inter-organizational approach: *coordination*, *cooperation*, and *collaboration*

For UNB, the human factors investigated relate to the three dimensions of interest—social, cognitive, and informational:

- *Social*: reputation risk, organizational alignment; and beliefs about other organizations: cultural restrictiveness, classification clearance, and technical clearance
- *Cognitive*: uncertainty risk, risk level threshold, attention overload, context confusion, task overload, override policy condition, times to observe, document, risk check, and publish, and organizational problem scorecard (i.e., indicator-score mapping)
- *Informational*: routine and non-routine events, classification level, ownership degree, uncertainty, accuracy, completeness, credibility, and technical impediment level

This portion of the deliverable only highlights which factors were considered. Further information regarding these factors for both approaches is found in the project-related reports [UNB1-UNB4, UofO1-UofO5].

3.4 Experiment Variables

For the actual experiment, the variables for the in-vivo simulation (UofO) consisted of the following:

- Two conditions related to problem-solving approach based on the types of tasks (coordination vs. collaboration)
- Two conditions related to the composition of pods[2] according to organizational type (homogeneous vs. mixed)
- The approach to decision making and inter-organization environment were influenced by four pod configurations:
  - (i) homogeneous pod, no inter-pod communication;
  - (ii) homogeneous pod, open inter-pod communication;
  - (iii) mixed organizations pod, no inter-pod communication; and
  - (iv) mixed organizations pod, open inter-pod communication
- Dependent variables for <u>problem solving processes</u>: satisfaction with problem solving process (individual, collective, and external panel), level of participation with each pod, level of participation between pods, time spent on problem

[2] A pod is composed of a group of individuals working together to solve a problem.

solving stages, pattern of engagement in problem solving stages, and task and group cohesion

- Dependent variables for problem solving outcomes: decision quality (individual, collective, and external panel), satisfaction with problem solving outcome (individual, collective, and external panel), level of agreement on outcome, changes in individual and collective goals, and time to reach decision

On the other hand, for the agent simulation, the effect of the various factors on consensus achievement was explored using these variables:

- Two conditions for each of the three factors-of-interest (randomized vs. constant)
- Eight factor configurations (all combinations of the three factors):
  - (i) social (constant), cognitive (constant), informational (constant);
  - (ii) social (randomized), cognitive (constant), informational (constant);
  - (iii) social (constant), cognitive (randomized), informational (constant);
  - (iv) social (constant), cognitive (constant), informational (randomized);
  - (v) social (randomized), cognitive (randomized), informational (constant);
  - (vi) social (randomized), cognitive (constant), informational (randomized);
  - (vii) social (constant), cognitive (randomized), informational (randomized); and
  - (viii) social (randomized), cognitive (randomized), informational (randomized)
- Randomization of key factors—social, cognitive, and informational—and the ability to keep certain factors constant and test the effect of another (or combinations)
- Number of execution runs for each configuration of the simulator: 30

3.5 Results

From the in-vivo work (UofO), it was found that there are challenges to SDM in terms of communication and resources required. Challenges in participating in a multi-organizational environment also increase as the diversity of the organizations increases: increased diversity of opinion leads to less agreement on decisions made, and increased time pressures when compared to working in a more organizationally homogeneous environment. The data from the experiment demonstrated that organizations could be “instructed” to solve tasks in either a collaborative or coordinated manner.

For the agent work (UNB), the most important dimension, i.e., the one that had the greatest effect on time to consensus was the cognitive dimension. This suggests that modelling the behaviour of agents to be more “empathetic” to another agent/organization’s perspective of an issue can be critical. Therefore, the impact of the cognitive can also be improved through training.

The results of both approaches have shown that, though different variables and case studies were considered, the effect of cognitive factors is the most important. This is encouraging as it suggests that the biggest roadblock to achieving coordination, cooperation, and collaboration is psychological, and could possibly be improved with training.

3.6 Summary

Both in-vivo and agent-based simulations are supported by literature, but each carries its own strengths and weaknesses. For example, agent-based simulation allows many different configurations to be tested at no additional cost once it has been implemented, and factors can be constantly modified, depending on the interface, without requiring changes to the underlying code base. This has been accomplished with the HSE. However, validating the underlying models themselves has proven more challenging: translating social and psychological theories is not always straightforward, and experts in these fields often do not agree on one set theory. In terms of in-vivo simulation, on the other hand, one clear disadvantage is that the experiment is more difficult, and costly, to repeat. However, rich data can be extracted from human participants and captured via video and audio recordings. This has great benefits in terms of testing new and existing theories.

Rather than competing approaches, in-vivo and agent-based simulations are highly complementary, especially for studies involving human-factors. With agent-based simulations (and computer simulations in general), there is greater flexibility for testing parameter configurations, with the added benefit that this is accomplished with little or no additional cost. Therefore, this approach can be used to test various parameter settings and potential “hunches” before selecting the setting(s) of most interest to be examined in real-life using in-vivo simulation. This combined approach would have the benefit of then extracting a more targeted data-set from human participants.

4 Evaluation of HSE Proof-of-Concept

The introduction highlights the project milestones and completion dates for the UNB component of the TIF project. These have been packaged into four deliverable reports, according to the schedule shown in Figure 1. This section provides an evaluation of the completed project for each report.

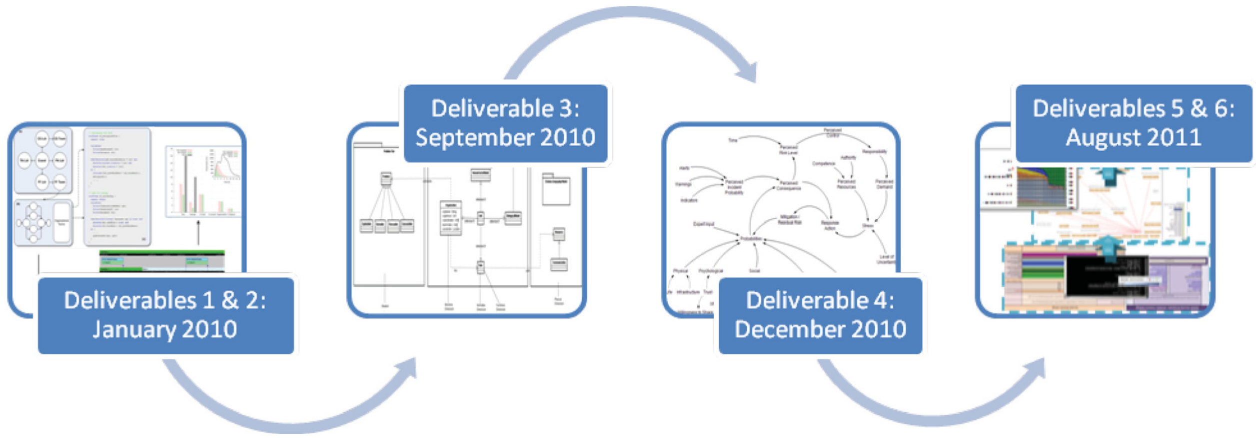

Figure 1: Deliverable Timeline

Each of the packages will be summarized briefly and considered according to four criteria:
(i) relevance,
(ii) (ii) feasibility,
(iii) (iii) utility, and
(iv) verifiability.

These assess the relevance of each report to the overall success of the project; the feasibility of various elements, e.g., whether or not an element could be modelled; the utility of various elements with respect to the project's main goal, e.g., did it help in understanding the effect of key factors; and, lastly, the verifiability of the artifacts produced. A summary of the overall benefits and limitations of the approach is presented at the end.

4.1 Deliverables 1 & 2

Project Title:

- Deliverable 1 -- Design of the HSE simulation (Oct 2009)
- Deliverable 2 -- Implementation of the HSE simulation (Jan 2010), [UNB1]

In this joint deliverable report, summarized in Table 2, the goal was to design and implement a proof-of-concept simulation in the area of emergency response. The decision was made to model the security scenario after the Harbour Siren exercise in Halifax. Using two multi-agent tools—OperA for modelling the organizations and norms, and Brahms for executing the simulation—the initial simulation was achieved (see Figure 2).

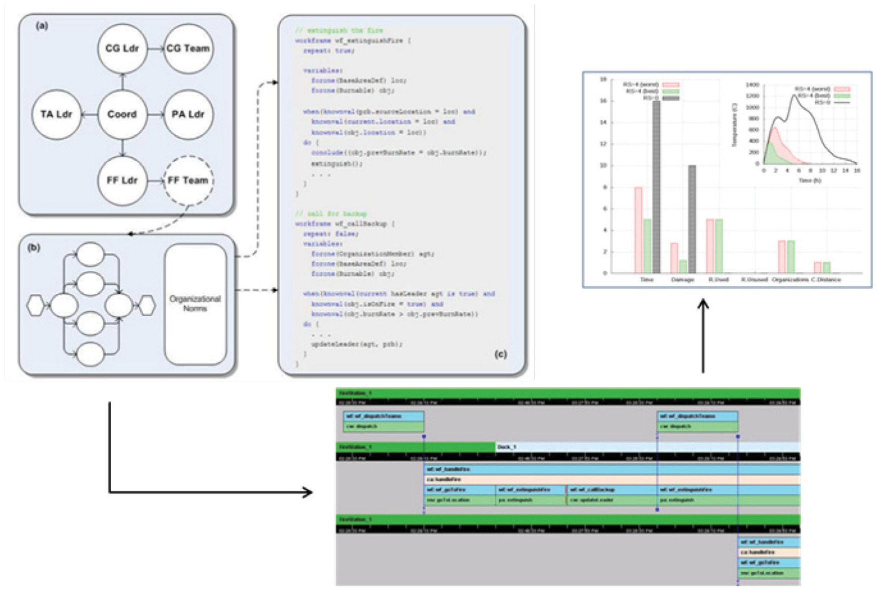

Figure 2: Original HSE Modelling & Simulation Process.

As part of the early work on investigating how to model an organization, a five-dimensional approach was created which considered the structural, functional, normative, human, and physical dimensions. In this early simulator, the structural and normative factors were examined, and a visualization tool created.

Table 2: Deliverables 1 & 2 Summary.

Factor	Deliverable Highlights
Objective	• Develop "proof-of-concept" simulation
Case Study	• Harbour Siren exercise
Timeline	• 0 to +2 (response and recovery)
M & S Tools	• OperA (Agent modelling framework) • Brahms (Agent simulation environment) o Workshop with Brahms creator

HSE Simulation (version 1)	• 5-D approach
	• Four rule sets (i.e., configurations)
	    o Structural and normative factors
	• Focus on response
	    o Organizations
	        ▪ Many agents per organization
	    o Processes
	        ▪ Basic
	        ▪ Not validated
	    o World events
	        ▪ Fire on a ship
	        ▪ Spread of contaminant
	    o Severity of disaster
	        ▪ Escalation as figure-of-merit

Visualization	• GIS map of harbour • Show response actions and communications • Timeline of agent actions

4.1.1 Evaluation

The proof-of-concept simulator development was essential as the starting point for the UNB portion of the project and ultimately led to the refinement of a central methodology to conduct policy-oriented agent-based simulation. It proved the feasibility and usefulness of having such simulations on a small-scale, but did not validate the assumptions made during the initial design and implementation stages. A consideration of the evaluation criteria appears below.

Relevance

- Created a simulator to test different configurations
- Explored different normative and structural factors

Feasibility

- Possible to model normative behaviours using OperA
- Possible to simulate work practice in multi-agent system using Brahms
- Not possible to collect real-world emergency response and defence workflows due to sensitivity of information

Utility

- Early HSE useful as a proof-of-concept; it showed the importance of the structural factor during emergency response
- The rule sets (i.e., configurations) provided a template for conducting experiments that was used in the final version of the HSE simulation

Verifiability

- Tool can compare different configurations and results match what is expected in reality
- Response actions and action-to-organization mappings were not validated

4.2 Deliverable 3

Project Title:

- Extension of the HSE simulation to include social, cognitive, and informational conceptual models (Sept 2010), [UNB2]

In this deliverable, summarized in Table 3, work towards extending the earlier HSE approach was presented. The main change was a shift in focus from response and recovery to threat detection, due to limited access to real-world information on the (often) sensitive processes related to response and recovery.

From this deliverable, the major artifacts included a new, extensible resource library (ERL[3]) framework (see Figure 3), showing how general development classes (e.g., Unit, Role, HumanFactor Model, and Organization) are linked and how they can be instantiated with various object instances (e.g., new organizations and human factors). This was critical to allow for more general-purpose simulation models, rather than scenario-specific models like the earlier simulation.

[3] Formerly, the emergency-response library

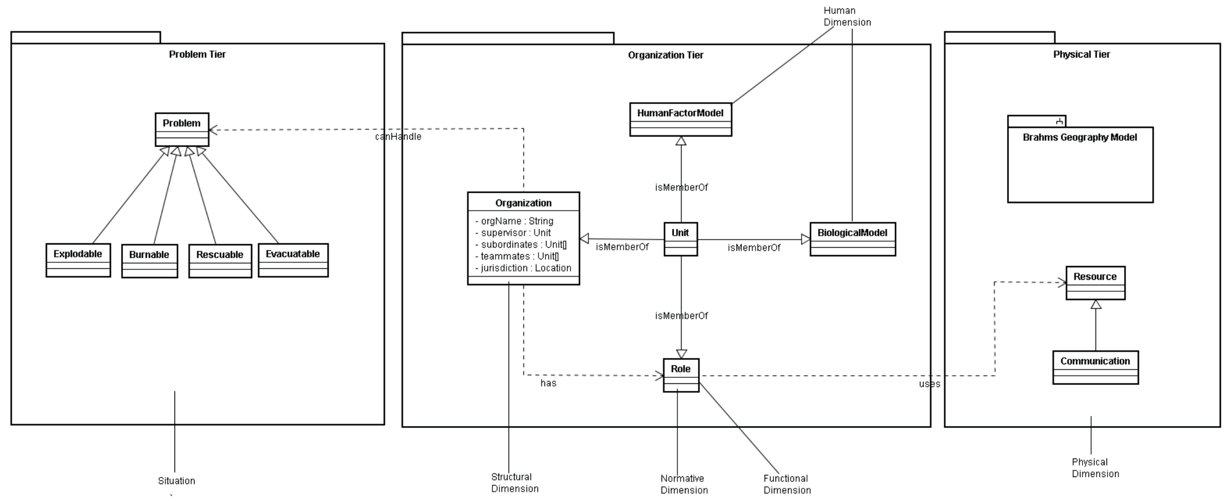

Figure 3: Early ERL Framework.

Human factor models were also developed using system dynamics, both to capture the feedback mechanisms and as a tool to communicate the model to experts, [Stress]. Moreover, work on the new threat-detection scenario was also begun, including developing and populating a problem-indicator matrix (the indicators related to specific types of problems) and an indicator-risk matrix (the risk level associated with a particular indicator). These laid the groundwork for future deliverables.

Table 3: Deliverable 3 Summary.

Factor	**Deliverable Highlights**
Objective	• Extending the HSE approach (from Deliverables 1 & 2)
Case Study	• Harbour security
Timeline	• -2 to 0 (preparation and detection)

Modelling Methodology	• 5-D approach
	• ERL (generic)
	  o Problem tier
	  o Organization tier
	  o Physical tier
	• Human factors
	  o System dynamics
	  o Stress model
	  o Culture model

Simulation	• Stress o System dynamics model
Scenario Development	• Problem-indicator matrix • Indicator-risk matrix

4.2.1 Evaluation

This deliverable resulted in key artifacts and methods, particularly the general ERL modelling component and the shift towards threat consensus. These insights led to a better understanding of

how to model fuzzy human-factor elements using system dynamics. However, it also highlighted the need to validate these fuzzy models. A consideration of the evaluation criteria appears below.

Relevance

- Extended the approach to adapt to multiple cases
- Incorporated all five dimensions into the simulation
- Shifted the focus from detection to consensus achievement
- Emphasis on soft modelling

Feasibility

- Possible to create a general framework using software engineering practices (URL-based)
- Possible to create and communicate soft models to experts using system dynamics

Utility

- Useful to have a single interface for multiple cases
- Stress model was useful as a proof-of-concept for the benefits of system dynamics in soft modelling

Verifiability

- The stress model helped highlight not only the need for soft model validation, but also the challenges it presents; for example, how the various factors of stress interrelate is not agreed upon by experts

4.3 Deliverable 4

Project Title:

- Verification of the extended HSE simulation (Dec 2010), [UNB3]

This deliverable centered on the verification and validation workshop. The scenario which was begun in the previous deliverable was extended by interviewing ex-naval members and included two variations: a domestic attack and an offshore attack. The scenario artifacts include event indicators, timelines, impediments to information sharing and indicator observation, and a level-0 diagram highlighting the ecosystem organizations of interest.

The mental process undertaken by each organizational agent was also developed at this stage. The four key processes that each organizational agent follows are as follows: observe (perceive an indicator either first-hand or via communication), document (record the fact that the indicator has been observed), risk check (test the indicator against a list of possible problems; list is unique to each organization), and publish (the potential to publish, i.e., share, the information with other organizations depending on need-to-know or need-to-share requirements).

Figure 4: Early Risk-Assessment Model.

At the workshop, these latest artifacts, including the risk-assessment model (see Figure 4), and selected artifacts from the previous deliverables were presented and scrutinized by experts from different fields and organizations as summarized in Table 4.

Table 4: Deliverable 4 Summary.

Factor	**Deliverable Highlights**
Objective	• Model extension • Scenario extension • Verification & Validation

Case Study	• Harbour security
	  o Domestic attack
	  o Offshore attack

Timeline	• -2 to 0 (preparation and detection)

Scenario Development	• Expert consultation
	  o Two ex-naval members
	• Two scenarios
	  o Domestic attack
	  o Offshore attack
	• Artifacts
	  o Event indicators
	  o Timeline
	  o Observation impediments
	  o Information-sharing impediments
	  o Level-0 diagram

Simulation Design	• System architecture diagram
	• Simulation process models (BPMN)
	  o Observe
	  o Document
	  o Risk check
	  o Publish

Verification & Validation Workshop	• Artifacts evaluated o 5-D approach o Modelling methodology o Human-factor modelling methodology o ERL architecture o Human-factor taxonomy o Stress model o Risk assessment model o Information sharing impediments o Observation impediments o Revised problem statement o Level-0 diagram o Publish-subscribe model o Simulation process models • Experts o Canadian Coast Guard o Marine Security Operations Center (MSOC) o Navy o Firefighters o Academia o Defence Scientists (RCMP) o Defence Scientists (M&S) o Defence Scientists (MDA) o Industry • Survey

4.3.1 Evaluation

The extended simulation capability was validated in a two-phase manner involving expert interviews and a verification and validation workshop with participants from multiple organizations. This deliverable provided the core situation being simulated and allowed for eliciting feedback on the approaches and assumptions made during the design process. A consideration of the evaluation criteria appears below.

Relevance

- Selected the key factors to be included in the next version of the HSE simulation
- Developed a scenario to test key cognitive, social, and informational factors

Feasibility

- Two plausible scenarios, with variations, were designed with the help of experts
- Continued using system dynamics for soft models
- A workshop with experts from various organizations was conducted as highlighted in Table 3

Utility

- Models were scrutinized by workshop members and feedback was provided
- Reaction from the community was positive; however, there was scepticism about whether such a simulation was possible

Verifiability

- The models and artifacts validated at the workshop are summarized in Table 3

4.4 Deliverables 5 & 6

Project Title:

- Deliverable 5 -- Analysis of the effect of key social, cognitive, and informational factors (Apr 2011)
- Deliverable 6 -- Analysis of the effect of security system relationship configurations on goal achievement (Aug 2011), [UNB4]

For the final deliverables, summarized in Table 5, the models presented at the workshop were refined based on written and verbal feedback. The biggest change was the refinement of the five-dimensional model to include seven dimensions: structural, functional, normative, social (formerly part of human), individual (formerly part of human), physical, and informational. Moreover, based on feedback, various properties were added to the informational dimension and served as factors that helped determine whether or not an agent would share/publish information about the indicator to other organizations.

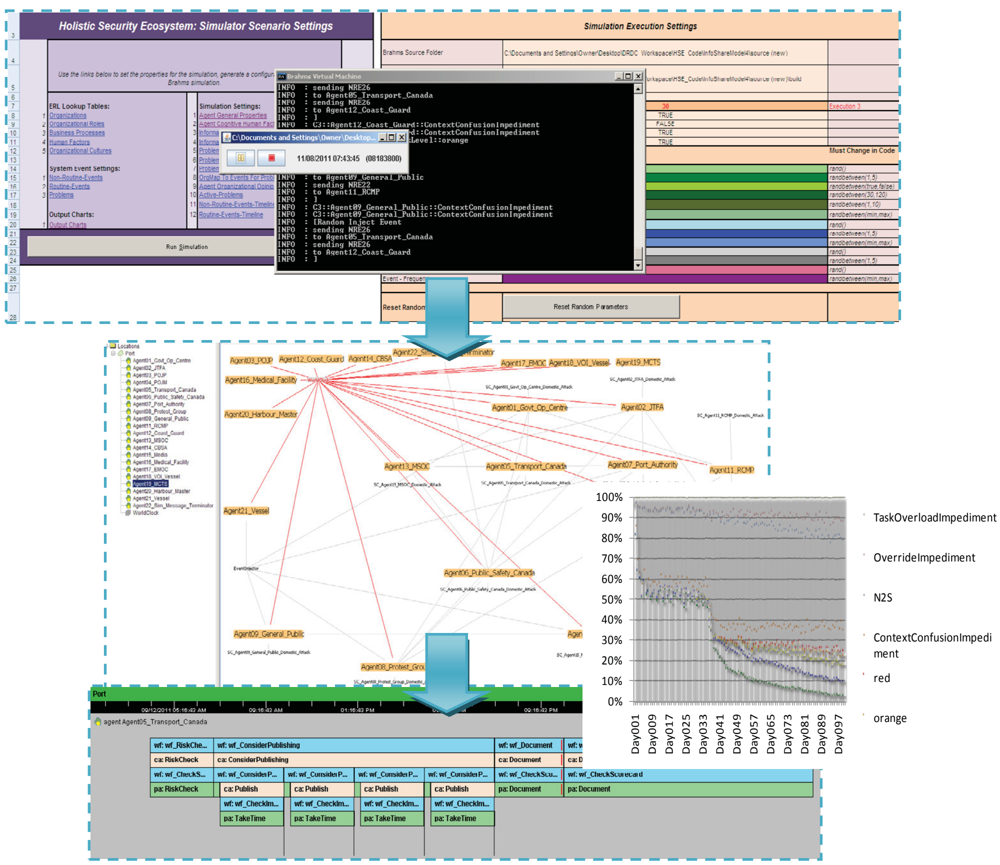

Figure 5: HSE Simulation Interface and Sample Output.

For Deliverable 5, the new simulation was implemented and presented (see Figure 5). It includes a spreadsheet front-end for selecting which models from the ERL to include in the simulation. It also provides an experiment control panel, where the various social, cognitive, and informational properties and factors can be turned on or off and also randomized.

For Deliverable 6, a set of eight experiments were run with specific combinations of factors, and the results were analyzed. It was found that cognitive factors had the greatest impact on consensus achievement in the simulation. Also, various visualization elements were able to be captured (i.e., C1 to C4), allowing for the analysis of system-level properties.

Table 5: Deliverables 5 & 6 Summary.

Factor	Deliverable Highlights
Objective	• Refine models based on V&V feedback • Simulation implementation • Simulation experiment design & results

Case Study	• Harbour security
	  ○ Domestic attack
	  ○ Offshore attack

Timeline	• -2 to 0 (preparation and detection)

Models Refined	• Expanded 5-D to 7-D
	• Added information properties
	  ○ Ownership degree
	  ○ Uncertainty
	  ○ Accuracy
	  ○ Completeness
	  ○ Credibility

Simulation	• Architectural components
	  ○ Excel interface
	  ○ Brahms code
	• Output (4 charts)
	  ○ C1: Perceived threat levels
	  ○ C2: Sharing events
	  ○ C3: Observation impediments
	  ○ C4: Publishing impediments

Experiments	• Parameter setting
	  ○ Social
	  ○ Cognitive
	  ○ Informational

4.4.1 Evaluation

The final deliverables incorporated the validated elements from the expert meetings into a working simulation of inter-organizational response. Deliverable 6 tested all possible combinations of cognitive, social, and informational factors within the simulation. This achieved the goals of the project, with results that were reasonable and based on large averages over a significant number of simulation runs. The HSE approach showed that agent-based programming is feasible for human-factor modelling. A consideration of the evaluation criteria appears below.

<u>Relevance</u>

- Implemented the models presented at the verification and validation workshop

- Tested the effect of various elements on the three key factors of interest: cognitive, social, and informational

<u>Feasibility</u>

- Tools had already been tested and developed (i.e., Brahms and ERL) and a familiar interface available (i.e., Excel)

<u>Utility</u>

- Platform to test the effects of various elements on the three key factors

<u>Verifiability</u>

- Individual models were validated during the workshop; however, their interactions were not validated
- Following the implementation, the simulation software was not exhaustively tested (e.g., black-box testing)

4.5 Overall Evaluation

The HSE simulation environment has accomplished the project goals. It simulated inter-organizational communication showing the impact of information observation and sharing on organizational risk assessment. Additionally, the human element was able to be incorporated, which is useful for future research efforts. The refined seven-dimensional model is novel and provides a methodology for exploring the complexities of organizations. The system dynamics approach to understanding causal relationships between human factors proved to be effective and useful in validation efforts. The implementation of the ERL based on the seven-dimensional model, business processes for information sharing, and human-factor models has shown to provide a basis for further agent simulation research in this area. Lastly, it provides a repeatable, computable tool for exploring and understanding human-factor effects through agent-based simulation.

The core benefits and limitations of the HSE approach are shown below:

4.5.1 Benefits

- General approach
  - Allows for the inclusion of new models and scenarios
  - Respects the complexity of reality through a seven-dimensional lens used to create interrelated models
- Spreadsheet interface
  - Allows for parameter variation and model selection
  - Hides underlying coding details from the user

4.5.2 Limitations

- Difficult to verify the interaction of multiple human-factor models
  - No agreed model for many of the human factors being investigated
  - No clear direction for validating the interplay of several interacting models
- Difficult for university researchers to get access to real-world data, such as actual business practices

5 Lessons Learned

The general reflection of the work is that the HSE-portion of the project has been successfully accomplished, especially with regards to the work on approaches and methods for building simulations that incorporate human-factor perspectives. This work, even as a proof-of-concept, may prove informative to researchers and theorists looking to experiment with best-practice discovery and policy analysis. A number of important challenges were encountered over the course of the project, and these have been summarized as lessons learned in this section, and are presented, as in the evaluation section, by report deliverable.

The lessons learned cover all phases of the project, from preliminary designs through to final outcomes, and aim to provide insights, particularly for future studies on incorporating human factors into simulations. The core deliverables have been explained in the section above and cover (i) the development of a proof-of-concept HSE simulation, (ii) the extension of the HSE simulation approach, (iii) the extension, verification, and validation of HSE models and scenarios, and finally (iv) the refinement of models and analysis of key factors using simulation experiments.

The following subsections describe the issues, outcomes, and lessons learned from each deliverable (or combined deliverables).

5.1 Deliverables 1 & 2

Project Title:

- Deliverable 1 -- Design of the HSE simulation (Oct 2009)
- Deliverable 2 -- Implementation of the HSE simulation (Jan 2010), [UNB1]

The early deliverables aimed to develop an initial simulation as a proof-of-concept, representing the plausibility of using simulations to understand the impact of various decisions and policies on an unfolding incident. The Harbour Siren (2009) exercise provided the backdrop scenario for the simulation, including key policies to explore. A small agent-oriented meta-organization was developed and a "what-if" analysis undertaken. The core challenge during this phase of the project was on the establishment of the initial methodology, and key issues and outcomes are shown in Table 6.

Table 6: Developing an Initial Methodology (Deliverables 1 & 2).

No.	Issues	Outcomes
1	What are the important variables?	Five Dimensional Modelling (5-D) • Organizational structure parameters • Normative parameters • Functional parameters • Human-factor parameters • Physical parameters
2	Availability of information • How to validate organizational process	Harbour Siren exercise • Significant progress was made following visit to Harbour

	models?	Siren exercise
3	Model details overwhelming • What level of detail to use?	Focused on important processes, not objects (e.g., telephone system)
4	What tools to use?	Learned about important tools • Brahms • OperA
5	What to measure? How to show results?	Rule sets (deontic logic) / charts

The first issue addressed the need to discover the key variables for the initial HSE approach. The primary outcome is the result of an investigation of modelling parameters from a multi-dimensional perspective. In particular, this led to the insight that at least five kinds of parameters would be essential for simulating organizations: (i) the organizational structure; (ii) the normative rules within that organization that govern the behaviour of its actors (i.e., organizational members); (iii) the functional role-based capacities of key actors; (iv) the elusive, yet important, "human-factor" elements; and (v) the everyday physical environmental objects and parameters. This "lens" has been used throughout the project, with some additions, and was particularly useful as a starting point for describing organizations.

The second challenge involved obtaining valid information from stakeholders to set core parameters. As there are security and cultural obstacles to information sharing for academic use, the solution for obtaining organizational data was to use a semi-ethnographic approach: participate in the Harbour Siren exercise (2009) as external academic observers. This provided core information for the scenario and valuable information through observation. This type of approach is considered appropriate, although very opportunistic. It would be better not to have needed to rely on participation in this exercise to secure the necessary modelling data.

The third issue addressed the level of detail to include in the simulation. At this stage, the simulation of meta-organization acting in a crisis situation represented a host of possible simulation perspectives, and the core dilemma of which elements of the 5-dimensional model to focus on presented a significant decision point. The result was to scope the work towards processes, rather than simulation of objects themselves. This downplayed the physical simulation dimension, while augmenting the functional and normative dimensions. As a result, it was possible to focus on select analyses of decision-making and what-if situations. This proved useful, as it translated directly to the requirements of the project and removed focus on simulation physics, which have many parameters that distract from the true purpose of the simulation.

The fourth issue involved the selection of appropriate modelling and simulation tools and technologies for the development of the HSE simulation. This refers primarily to the selection of an agent-oriented methodology for organizational modelling (OperA, [Dignum]) and simulation (Brahms, [Clancey1998]). OperA represents an easy to understand method of developing simulation parameters that specially concentrate on norms, structures, and role functions. Brahms provides an agent engine based on recent advances in multi-agent systems and AI research, especially the concept of work-practices, or what people "actually" do, rather than what their goals are. These tools, when combined, represent a very considerable technology for exploring real-world organizations through computer simulation.

The fifth issue involved the decision of which outcome metrics to derive from the simulation and how best to present them. It was decided to perform an assessment based on deontic logic (i.e., permission, obligation, and prohibition) of the normative rule/policy decisions of agents, as well

as the structural makeup of agent organizations. These allowed for the simulation of specific what-if scenarios and resulted in targeting the "cause-and-effect" of the simulation results, which were presented as graphs using metrics such as time-to-solve problem, amount of damage, resources used/unused, and also problem escalation level. This outcome was useful in discussing the simulation with stakeholders.

5.1.1 General Comments

In general, this phase of the simulation provided the proof that simulations of human organizations are useful in conducting what-if analysis of important decision factors. Additionally, the human factors incorporated into the simulation at this point were facilitated by the use of cognitive agent architecture, Brahms. The simulation and methodology had merit, but the lack of real-world data resulted in a change of scenario from response to prevention in June 2010.

5.2 Deliverable 3

Project Title:

- Extension of the HSE simulation to include social, cognitive, and informational conceptual models (Sept 2010), [UNB2]

Having an initial proof-of-concept provided the foundation for a base framework for the HSE approach. The next step involved the extension of the HSE approach, from a modelling perspective. The primary concerns at this point involved making the approach generic and expanding the human element in the approach, as highlighted in Table 7.

Table 7: Extending the HSE Approach (Deliverable 3).

<table>
<tr><th>No.</th><th>Issues</th><th>Outcomes</th></tr>
<tr><td>1</td><td>How to make process more general/generic?</td><td>ERL (reusable models)</td></tr>
<tr><td>2</td><td>Elements missing from 5D approach?
Technology
Information</td><td>Seven-Dimensional Modelling (7-D) (Deliverables 5 & 6)
Information added to model
Technology part of physical
Human separated into individual (including psychological) and social</td></tr>
<tr><td>3</td><td>How to capture human elements?</td><td>Exploration of system dynamics
Stress model
High-level human-factor models</td></tr>
<tr><td>4</td><td>How to overcome lack of information?</td><td>Change scenario from response to prevention</td></tr>
</table>

		o Scenario development o Added expert information helps scenario o Read literature on Harbour procedures

The first issue involved a study of possibilities for generalizing the original simulation, allowing the approach to be applicable to future scenarios. The outcome was a refined process and a decision to focus on a general-purpose simulation library: the Extensible-Resource Library (ERL) for emergency-response simulations. This library guided a redesign of the core simulation components, having in view a wider perspective. The key lesson is the need to address generality in simulations early in the design process.

The second issue involved the expansion of the five-dimensional approach to incorporate two new factors. The properties of technology and information were both unaccounted for, but were considered particularly relevant factors. As a result, the seven-dimensional modelling methodology was created, adding information as its own dimension and incorporating technology as part of the physical dimension. Additionally, the human perspective was separated into individual properties (including psychological) and social properties. The core lesson involves the creation of a holistic lens for modelling organizations. It is recommended that future works adopt the seven-dimensional approach.

The third issue involved the methods to describe and capture the fuzzy human models related to the social, cognitive, and informational factors needed in the simulation. This led to an exploration of specific model parameters and a selection of an approach to understand the overall impact of these parameters on the model. The system dynamics approach was applied to modelling initial cognitive factors, namely stress [Stress], in a fashion that allows for validation by experts. It was discovered that the approach indeed was useful to incorporate high-level human factors, enabling the extraction of core components, as well as the relationships between them, and allowing for the eventual inclusion of cognitive-factor dynamics into the simulation at runtime.

The fourth issue involved addressing the lack of information for a general-purpose scenario, loosely related to the earlier one. The outcome was to switch the target focus for the simulation away from complicated response-activity modelling, which requires detailed business practices that may be proprietary or security-sensitive. The new focus involved looking at the issue of prevention, particularly achieving consensus across the ecosystem about whether or not a particular security threat was imminent. This still involved gaining access to expert information through third-party discussions and publicly available literature on harbour procedures. Combined, these proved to be useful for information extraction and scenario development.

5.2.1 General Comments

The central challenge of the third deliverable was to enhance the HSE approach. The general-purpose goal of the system designs and models was carried through to the remaining deliverables and full-testing of the generality remains to be explored in future scenarios. The need for generality, however, brings with it an added overhead that requires early simulation efforts to be reworked in order to fit into the new framework.

5.3 Deliverable 4

Project Title:

- Verification of the extended HSE simulation (Dec 2010), [UNB3]

Having refined the HSE approach in the previous deliverable, the subsequent phase involved verification and validation of the approach and associated models. The decision was to conduct an expert validation. This resulted in the 2010 roundtable discussion and presentations, attended by experts from governmental agencies, industry, and academia. Useful recommendations were brought forward during the workshop, and the core challenges in conducting the session are seen in Table 8.

Table 8: Verification and Validation of the HSE Approach (Deliverable 4).

No.	Issues	Outcomes

1	• How to gather information from expert group?	• Survey was conducted based on meeting
		  • Iterative validation would have been useful
		  • Need for further validations, such as presenting responses to feedback of the expert group
		• Surveys were useful in gathering feedback

2	• Selecting a core expert group	• Volunteers o Mixed group

3	• How to structure information for expert validation?
	  o Stakeholder customized data views
		• Used established methods of information display
		  o System Dynamics
		  o Business Process Modelling Notation

4	• Validating simulation was not achievable (initial goal)
	  o Timelines
	  o New scenario
		• Validation of models prior to implementation
		• More psychological input needed from experts

The first issue centered on the information gathering and knowledge acquisition problem. It was essential to decide which method to use to elicit feedback from the participants in the expert group. Ultimately, it was decided that a survey, in combination with the live roundtable discussion, would be used. The assessment of this combined approach is that it allows for targeted, yet non-restrictive, verbal feedback during the session (e.g., the survey can guide discussions), and also provides a useful follow-up mechanism for recording private reservations and recommendations. However, it would have been useful to conduct further sessions, so that the outcomes at later stages of the project could be iteratively validated.

The second issue involved the problem of deciding which experts should be included, and gaining access to these experts for the workshop. In the end, a mixed group of volunteers from various organizations were in attendance; however, it is noted that there were relatively few participants from the psychological community, an important expert class.

The third challenge involved information presentation and dissemination to the expert group, and particularly how to structure this information for stakeholders with varying viewpoints. The outcome was to focus on using well-established information display mechanisms, specifically system dynamics causal loop diagrams and the business process modelling notation (BPMN). These were found to be very adequate for describing concepts and workflows.

The fourth challenge involved validating the simulation at the workshop, as the new simulation remained to be implemented. The event timelines and general scenario were presented, but were not discussed at length. Instead, the human-factor models were the central focus, and only a short discussion of the scenario-specific artifacts was conducted. This allowed for the maximization of the pool of experts, as scenario-specific artifacts can easily change within and across scenarios and are not as general as the human-factor models.

5.3.1 General Comments

In general, the verification and validation went well allowing the simulation implementation to proceed. As mentioned, further engagement of psychologists remains essential, particularly as the effect of cognitive factors is a significant simulation directive. Future research is encouraged to engage more closely with the psychological community.

5.4 Deliverables 5 & 6

Project Title:

- Deliverable 5 – Analysis of the effect of key social, cognitive, and informational factors (Apr 2011)
- Deliverable 6 – Analysis of the effect of security system relationship configurations on goal achievement (Aug 2011), [UNB4]

Following verification and validation of the approaches the remaining deliverables centered on the development and implementation of the extended HSE simulation incorporating feedback from the expert discussions into the models. The simulation design included the following architecture elements: parameter selection and execution in a spreadsheet interface, base control functions for configuring experiments and selecting ERL models, the multi-agent simulation environment, and data extraction and visualization for post-simulation analysis. These were implemented and tested on core experiments that varied levels of the key social, cognitive, and informational factors. The focus on consensus provided the output function as to whether or not

the factors had an impact on the achievement of distributed consensus. The central challenges and outcomes for this deliverable are shown in Table 9.

Table 9: Model Refinement, Simulation Implementation, and Experiments (Deliverables 5 & 6).

No.	Issues	Outcome
1	• How to make a general simulator?	• Systems architecture refinement
2	• How to allow for interfacing with non-programmers?	• Using front-end parameter selection environment o Excel spreadsheet
3	• How to select the right tools for building a general simulator?	• Used tools that provided work practice agents o Other tools available
4	• How to incorporate system dynamic models into new simulation?	• Embedded system dynamics within agent code as a process o Should be separated to allow for non-code changes (modularity)
5	• How to get more out of the simulation than you put into it? o How to avoid effect of hard-coded solution?	• Stochasticity added to parameters o Randomness o Noise o Impediments to publishing and observation o “Goldilocks” factor
6	• How to test key factors? o Social o Cognitive o Informational	• Isolating the effect of each factor through combination analysis o Testing all possible combinations of the three factors by manipulating whether or not the factor is randomized

The first issue involved implementing a general simulator, and the outcome was revised simulation architecture. In revising the architecture, the consideration that the users of the simulation environment would not be code developers was a key concept. This led to the extraction of core variables from being hard-coded in the Brahms agent environment to being adjustable from an external interface (Microsoft Excel). The outcome is a communication framework between the two platforms that abstracts coding details and allows for easy parameter changes. It also enforces the requirement that lower-level code be general so that it can cope with new models and scenarios.

The second issue relates more specifically to the spreadsheet interface for non-programmers, as discussed in the previous paragraph. The two are closely linked, and, as indicated, Microsoft Excel was selected as the interface for users due to its familiarity and built-in programming interface. The latter proved invaluable for connecting the spreadsheet with the Brahms agent environment.

The third issue continued to extend the generality requirement by considering tools to produce a general-purpose simulation framework. The solution was to continue with Brahms as a multi-agent platform, but to add dynamics through an external program. This was satisfactorily achieved during this phase, and the combination of an internal simulator and an external variable controller is a useful approach.

The fourth issue involved the method of incorporating system dynamics into the simulation. The system dynamic models validated were in the form of causal feedback loop diagrams, which needed to be translated into program variables in order to be used. The process of making use of these diagrams was a challenge and the solution was to embed the dynamics as a higher-level process related to the original business process models. It is noted though that this approach is still too tightly coupled to the code and needs to be generalized further to allow for fully changing these dynamics from the external interface.

The fifth issue involved considering how to get more out of the simulation than was put into it, particularly how to avoid the effect of hard-coded results. In addition to adding system dynamics, stochastic approaches proved useful, and randomness was added to the parameters based on the particular experiment being run. Noise was also added to the system in terms of increasing the levels of communication which led to an increase in observation impediments (overload), for example, and also using the "Goldilocks" principle for cognitive models, [UNB4]. These in turn influenced the levels of information-sharing, enabling non-trivial results from the simulation, while still allowing factors to be tuned in the spreadsheet interface.

The sixth and final issue was how to test key parameters of the simulation to discover the impact of the social, cognitive, and informational factors. The solution was to explore these factors through combination analysis, specifically by varying whether or not each factor is randomized. This was done for all possible combinations, which is easily computable as there are only eight combinations to test (2^3). Additionally, for each combination, the simulator was executed a significant number of times (30) to produce statistically sound averages. The lesson learned is that this is an approach that benefitted highly from the initial work in generalizing the simulator and its controller, eventually allowing access to parameters that could be changed in this fashion. Moreover, more fine-grained exploration is also possible for sub factors, by turning their randomization on or off, rather than turning the randomization of whole classes of factors on or off (i.e., social, cognitive, and informational).

5.4.1 General Comments

The overall comment is that, as a proof-of-concept, the simulation works well and allows for modifying parameters easily. The use of the front-end interface allowed for closing the loop from parameter setting through to achieving results, without the user needing to be concerned with the underlying code. The results mapped well to real-world understanding and intuition of how the social, cognitive, and informational factors may impact a decision-maker. Furthermore, there is some value to the simulation in teaching the importance of the cognitive dimension on collaboration. However, several parameters remain to be explored by future researchers, including the impact of need-to-share and need-to-know communication paradigms.

Moving forward, extensions to the HSE approach should involve a refinement of parameters of interest, an expert validation of these refined models in system dynamics, and code verification under multiple conditions using white-box and black-box software testing.

6 Conclusion

The Holistic Security Ecosystem (HSE) portion of the TIF project was tasked with the goal of examining joint-organizational systems from both a top-down (i.e., individual) and bottom-up (i.e., system) perspective. It focused on the development of a computer-simulation approach to explore the effect of key social, cognitive, and informational factors present in individual agents (i.e., the individual-level) on inter-organizational efforts (i.e., the system-level), in particular consensus achievement through information sharing. The focus of the simulation was on whether or not agents with bounded rationality, only witnessing portions of the unfolding situation, in conjunction with other agents and based on the simulation settings; could collectively agree that a threat to the harbour was imminent. The experimental results show that the cognitive factor has the greatest impact on consensus achievement, though social and informational factors are also important.

The research to arrive at the HSE tool was conducted in six stages, as presented in previous deliverables, and culminates with a detailed multi-agent simulation involving high-functioning work-practice agents, following organizational workflows, and being influenced by social, cognitive, and informational factors. Such a simulation can help to elicit important information about how these core factors relate to one another and ultimately impact the system. This suggests that continued exploration using computer simulations is beneficial. Additionally, the HSE approach provides a core methodology for constructing such simulations, and has the potential to be adapted for future experiments at relatively low cost.

The lessons learned from this work are threefold: (i) more focus on human factors through simulation is necessary to better explore the complex interplay between human factors and meta-organizational design; (ii) more focus on human-factor model validation is needed to add credibility to the results; and (iii) more information on organizational procedures is needed to create meaningful functional models that can be "operationalized." These will lead to an improved understanding of the human element and its impact on joint-organizational endeavours.

References

[1] [TIFProposal] Modelling Meta-Organizational Collaboration and Decision Making. Technology Investment Fund (TIF) Project Proposal. 2007.

[2] [UNB1] Bicocchi, N., Ross, W., Ulieru, M. “Modelling and Simulating Organizations in Emergency-Response Operations.” TIF Project Deliverable 1&2. January 2010.

[3] [UNB2] Morris, A., Ross, W., Ulieru, M. “Extending Modelling and Simulation Capabilities for a Generic Harbour Domain.” TIF Project Deliverable 3. August 2010.

[4] [UNB3] Morris, A., Ross, W., Ulieru, M. “Modelling Public Security Operations: Verification & Validation of the Extended HSE Simulation.” TIF Project Deliverable 4. November 6, 2010.

[5] [UNB4] Morris, A., Ross, W., Ulieru, M. “Analysis of the Effect of Key Social, Cognitive, and Informational Factors with Security System Relationship Configurations for Goal Achievement.” Deliverable 5&6. August 2011.

[6] [UofO1] Lemyre, L., et al. “Synthesis of Case Studies to form a SDM framework.” Deliverable 1. April 2010.

[7] [UofO2] Lemyre, L., et al. “Development of an experimental plan for in vivo exercise and simulation.” Deliverable 2. June 2010.

[8] [UofO3] Lemyre, L, et al. “Testing the Shared Decision Making Framework in vivo.” Deliverable 3. March 2011.

[9] [UofO4] Lemyre, L, et al. “Modeling of Communication and Decision Functions within a Shared Decision-making (SDM) Framework.” Deliverable 4. August 2011.

[10] [UofO5] Lemyre, L, et al. “Creation of a user friendly knowledge tool.” Deliverable 5. March 2011.

[11] [Checkland1] Checkland, Peter, "Soft Systems Methodology: A Thirty Year Retrospective," Systems Research and Behavioral Science Syst. Res. Vol. 17, S11-S58, 2000.

[12] [Checkland2] Checkland, Peter and John Poulter, "Soft Systems Methodology," Systems Approaches to Managing Change: A Practical Guide, Ed. Martin Reynolds and Sue Holwell, London: Springer, 2010, 191-242.

[13] [EARF] Enterprise Architecture Research Forum, “Enterprise Architecture Definition,” February 2011, http://earf.meraka.org.za/earfhome/our-projects-1/completed-projects

[14] [Handley] Handley, Holly A. H., “HSI in Network Enabled Capability (NEC): The Human View,” NATO Human Factors & Medicine Panel (Research Technical Group 155), February 2010.

[15] [MoDAF] MoDAF, The Human View Handbook for MODAF, July 15, 2008. http://www.hfidtc.com/MoDAF/HV%20Handbook%20First%20Issue.pdf

[16] [DoDAF] DoDAF, The DoDAF Architectural Framework Version 2.0, 2010. http://dodcio.defense.gov/sites/dodaf20/products/DoDAF_2-0_web.pdf

[17] [Baumgarten] Baumgarten, E. and Silverman, S.J., “Dynamic DoDAF and Executable Architectures,” IEEE Military Communications Conference, 2007.

[18] [Glazner] Glazner, C.G., “Understanding enterprise behavior using hybrid simulation of enterprise architecture,” MIT PhD Thesis, 2009.

[19] [Scholz-Reiter] Scholz-Reiter, B. and Stickel, E., (eds.), Business Process Modelling. Springer-Verlag, Berlin (1996).

[20] [Orman] Orman, L. V., “A Model Management Approach to Business Process Reengineering,” in: Proceedings of the American Conference on Information Systems, Pittsburgh (August 1995).

[21] [Giaglis] Giaglis, George M., "A Taxonomy of Business Process Modeling and Information Systems Modeling Techniques," International Journal of Flexible Manufacturing Systems, Springer Netherlands, pp. 209 - 228, Vol. 13 (2), 2001.

[22] [Intalio] Intalio, “Business Process Management System (BPMS),” Intalio BPMS homepage, February 2012. http://www.intalio.com/bpms

[23] [ARIS] ARIS homepage, February 2012. http://www.softwareag.com/corporate/products/aris_platform/default.asp

[24] [Owen] Owen, Martin and Jog Raj,“BPMN and Business Process Management: An Introduction to the New Business Process Modeling Standard,” Telelogic white paper, June 2006. http://www.osiris-consultores.cl/Telelogic/6_BPMN%26BPM.pdf

[25] [Santos] Santos, P.S., J.P.A. Almeida, and G. Guizzardi, "An Ontology-Based Semantic Foundation for Organizational Structure Modeling in the ARIS Method," Enterprise Distributed Object Computing Conference Workshops (EDOCW), 2010 14th IEEE International , vol., no., pp.272-282, 25-29 Oct. 2010.

[26] [Borshchev] Borshchev, A. and A. Filippov, “From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools.” The 22nd International Conference of the System Dynamics Society, July 25 - 29, 2004, Oxford, England.

[27] [Ferber] Ferber, Jacques, Olivier Gutknecht, and Fabien Michel, “From Agents to Organizations: an Organizational View of Multi-Agent Systems,” Agent-Oriented Software Engineering (AOSE) IV, Ed. P. Giorgini, Jorg Muller, and James Odell, Melbourne: LNCS 2935, pp. 214-230, 2004.

[28] [Dignum] Dignum, Virginia, “A model for organizational interaction: based on agents, founded in logic,” Ph.D. Dissertation, Proefschrift Universiteit Utrecht, 2003. http://igitur-archive.library.uu.nl/dissertations/2003-1218-115420/inhoud.htm

[29] [Putten] van Putten, B.J., V. Dignum, M. Sierhuis, and S. Wolfe, “OperA and Brahms: A Symphony?,” Agent-Oriented Software Engineering IX, Lecture Notes in Computer Science, Vol 5386, Springer, pp. 257 – 271, 2009.

[30] [Stress] Morris, A., W. Ross, and M. Ulieru, “A System Dynamics View of Stress: Towards Human-Factor Modeling with Computer Agents,” 2010 IEEE International Conference on Systems Man and Cybernetics (SMC), pp. 4369-4374.

[31] [Marshall] Marshall, J. Living systemic thinking: exploring quality in first-person action research. Action Research Vol. 2 No. 3, pp.305—325, 2004.

[32] [Altrichter] Altrichter, H. and Kemmis, S. and McTaggart, R. and Zuber-Skerritt, O. The Learning Organization. Vol 9 Iss 3 pp.125—131, MCB UP Ltd. 2002.

[33] [Gronhaug] Gronhaug, K. and Olson, O. Action research and knowledge creation: merits and challenges. Qualitative Market Research: An International Journal. Vol. 2 Iss 1, pp.6—14, MCB UP Ltd. 1999.

[34] [Vicente] K.J. Vicente, The human factor: revolutionizing the way people live with technology, Routledge, 2004.

[35] [Jamieson] Jamieson, G.A. Bridging the gap between cognitive work analysis and ecological interface design. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Vol 47, Iss 3, pp.273—277, SAGE Publications. 2003.

[36] [Culture] Morris, A. and Ross, W. and Ulieru, M. Modelling culture in multi-agent organizations. Workshop on Agent-Based Modeling for Policy Engineering (AMPLE 2011), p81, 2011.

[37] [CARModel] Pigeau, R. and McCann, C. Re-conceptualizing command and control. Canadian Military Journal, Vol 3, Iss 1, pp.53—64, 2002.

[38] [Sterman2002] Sterman, J. Business Dynamics-Systems Thinking and Modeling for a Complex World, McGraw-Hill, Inc. 2000.

[39] [Balaji] Balaji, P. and Srinivasan, D. An Introduction to Multi-Agent Systems, Innovations in Multi-Agent Systems and Applications-1, pp1—27, Springer, 2010.

[40] [Wooldridge] M. Wooldridge and N.R. Jennings, Intelligent agents: Theory and practice, Knowledge engineering review 10 (1995), no. 2, 115--152.

[41] [Shoham] Shoham, Y. and Leyton-Brown, K. Multiagent systems: Algorithmic, game-theoretic, and logical foundations, Cambridge Univ Press, 2009.

[42] [Bryson] J. Bryson, “Cross-paradigm analysis of autonomous agent architecture,” Journal of Experimental & Theoretical Artificial Intelligence, vol. 12, no. 2, pp. 165-189, Apr. 2000.

[43] [Jason] Bordini, R.H., Hubner, J.F., and Wooldridge, M. Programming multi-agent systems in AgentSpeak using Jason, Vol 8, Wiley-Interscience, 2008.

[44] [Brahms] Clancey, W.J. and Sachs, P. and Sierhuis, M. and Van Hoof, R. Brahms: Simulating practice for work systems design, International Journal of Human Computer Studies, Vol. 49, Iss 6, pp.831—866, London; San Diego: Academic Press, c1994-, 1998.

[45] [Rao] Rao, A.S. and Georgeff, M.P. BDI agents: From theory to practice, Proceedings of the first international conference on multi-agent systems (ICMAS-95), pp. 312—319, San Francisco, 1995.

[46] [Scholl] Scholl, H.J. Agent-based and system dynamics modeling: A call for cross study and joint research, Proceedings of the 34th Annual Hawaii International Conference on System Sciences, p.8, IEEE, 2001.

[47] [Kraus] Kraus, S. Strategic negotiation in multiagent environments, The MIT Press, 2001.

[48] [Rubenstein] Rosenchein, JS and Zlotkin, G. Rules of Encounter, MIT Press, 1994.

[49] [Fedrizzi] Fedrizzi, M. and Fedrizzi, M. and Pereira, R. and Brunelli, M. The dynamics of consensus in group decision making: investigating the pairwise interactions between fuzzy preferences, Preferences and Decisions, pp.159—182, Springer, 2010.

[50] [Campanella] Campanella, G. and Araujo, T. and Pereira, R.A.M. The soft consensus model: dynamics, complexity, and modularity. 2010.

[51] [Blondel] Blondel, V.D. and Hendrickx, J.M. and Tsitsiklis, J.N. On Krause's multi-agent consensus model with state-dependent connectivity, Automatic Control, IEEE Transactions on, Vol 54, Iss 11, pp2586—2597, IEEE, 2009.

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More so than engineered systems, human factors, and specifically having humans-in-the-loop, can lead to unforeseen behaviours resulting in unexpected organizational failures. In the world of emergency response, these failures may be related not only to response activities, but also to information processing and sharing that consequently undermine the organizational ecosystems' situational awareness of unfolding events. The TIF project, Modelling Public Security Operations, has the goal of accounting for the human factor by more fully exploring its inherent complexity through experiments and simulations. This work reviews the development of a new capability in this area using computer simulation, as well as the lessons learned from this effort. It represents a detailed proof-of-concept into how human factors can be explored through multi-agent systems. The modelling and simulation challenge remains that more research on human factors must be conducted, including work to support improved validation methods for computer human-factor models.

Plus que les systèmes sophistiqués, les facteurs humains, et plus particulièrement lorsque des humains interviennent, peuvent mener à des comportements imprévus entraînant des échecs organisationnels imprévus. Dans le monde des interventions d'urgence, ces échecs peuvent être reliés non seulement aux activités d'intervention, mais aussi au traitement et à l'échange de l'information qui minent la capacité de l'organisation à jauger la situation à mesure qu'elle évolue. Le projet FIT, la modélisation des opérations de sécurité publique, vise à tenir compte du facteur humain en examinant plus amplement sa complexité inhérente au moyen d'expériences et de simulations. Le présent travail consiste à examiner le développement d'une nouvelle capacité dans ce domaine au moyen d'une simulation informatisée ainsi que des leçons retenues de cet exercice. Il valide le principe selon lequel les facteurs humains peuvent être étudiés au moyen de systèmes multi-agents. Modélisation et simulation ou pas, plus de recherches sur les facteurs humains doivent être faites, y compris des travaux pour étayer de meilleures méthodes de validation pour les modèles informatisées des facteurs humains.

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